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Intraoperative electromyographic monitoring to optimize safe lumbar pedicle screw placement – a retrospective analysis

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Abstract

Background: The foremost concern of a surgeon during pedicle screw fixation is safety. Assistive modalities, especially intraoperative electromyographic monitoring (EMG) can function as an essential tool to recognize screw malposition that compromise neural integrity, so that the screws can be repositioned immediately rather than later. We intend to study the efficacy of intraoperative EMG monitoring to detect potential pedicle breach and evaluate whether reoperation rates were significantly reduced.

Methods: Retrospectively, patients who underwent posterior stabilization with pedicle screws for various pathologies were analysed and those with screws among L1-S1 levels were shortlisted. They were divided into two groups. Group 1 included patients in whom trigger EMG (t-EMG) was used to confirm appropriate screw placement and Group 2 included those in whom it was not used. Responses to t-EMG and corresponding stimulation thresholds were recorded for Group 1 patients. The sensitivity and specificity of the test was calculated. Reoperation rates due to postoperative neurologic compromise caused by malpositioned screws were compared between both the groups.

Results: A total of 518 patients had 3112 pedicle screws between L1-S1 levels. Among Group 1 [$n = 296$; Screws = 1856], 145 screws (7.8%) showed a positive response for t-EMG at stimulation thresholds ranging between 2.6 to 19.8 mA. The sensitivity and specificity of t-EMG to diagnose potential pedicle breach was found to be 93.33% and 92.88% respectively. Only one patient among Group 1 required reoperation. However, among Group 2 [$n = 222$; screws = 1256], six patients required reoperation. This indicated a significant decrease in the number of malpositioned screws that caused neurological compromise [$p = 0.02$], leading to subsequent decrease in reoperation rates [$p = 0.04$] among Group 1 patients.

Conclusions: Trigger EMG is well efficient in detecting potential pedicle screw breaches that might endanger neural integrity. In combination with palpatory and radiographic assessment, it will certainly aid safe and secure pedicle screw placement. It can also efficiently reduce reoperation rates due to neurologic compromise provoked by a malpositioned screw.

Keywords: Electromyography, Neuromonitoring, Neurologic manifestations, Neurophysiology, Pedicle screws

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Background

Utmost care needs to be taken during pedicle screw placement to prevent potential damage to neural structures that closely approximate the bony pedicle. Pedicle screw technique has evolved over time and experience; however, “free-hand” technique is most widely practiced [1–5]. This technique involves visual identification of certain anatomical landmarks to find an appropriate entry point and then preparing the pedicle for screw placement [6, 7]. Whether the instruments used or the screw itself had breached the pedicle, is completely dependent on surgeon’s perception. Hence, considerable expertise is required to safely perform this technique.

Even though, intraoperative confirmation of secure screw placement can be obtained using fluoroscopic images, neural integrity or compromise needs to be checked. Moreover, completely depending on fluoroscopic images may not be appropriate, especially when proper anatomy cannot be visualized. Therefore, we believe that intraoperative electromyographic monitoring (EMG) can be an essential tool to recognize screw malposition that compromise neural integrity [8, 9]. Such detection gives a warning so that the screws can be repositioned immediately rather than later [10]. We intend to study the efficacy of intraoperative EMG monitoring to detect potential pedicle breach during free-hand lumbar pedicle screw placement and evaluate whether reoperation rates were significantly reduced.

Methods

We retrospectively reviewed data of all patients who underwent posterior instrumentation with pedicle screw constructs for various pathologies at our institution over a period of time. Their preoperative x-rays and MRI were evaluated. The indications of surgery included:

- a) Degenerative spondylosis,
- b) Spondylolisthesis (\geq grade 1),
- c) Spondylodiscitis and
- d) Tumours.

Only those patients with pedicle screws in L1-S1 levels were shortlisted and a sample containing 518 patients was obtained. They were divided into two groups based on intraoperative EMG monitoring. EMG monitoring was utilized based on the availability of neuromonitoring system and the operating personnel. Those patients in whom intraoperative EMG was used were Group 1 (Experimental group) and the remaining patients were Group 2 (Control group).

We excluded:

- a) Those patients with dysmorphic pedicle features, such as in congenital scoliosis,

- b) Those in whom minimally invasive percutaneous screw insertion was performed and
- c) Those with pedicle screws in vertebrae other than L1-S1.

Surgeries were performed by five experienced orthopaedic surgeons and their procedure to apply pedicle screw was unanimous. Although, we do both open surgery with free hand technique and minimally invasive surgery (MIS) with percutaneous screw insertion under fluoroscopic guidance, we only included patients in whom open surgery with free hand technique was used to place the screws. All surgeons identified bony landmarks including pars, transverse process and facet joints before making the entry point. Partial infero-lateral corticotomy of the superior facet was performed in line with the mid-point of transverse process to identify the appropriate entry point. Following entry, the pedicle was probed and walls were felt using a pedicle sound to assess structural integrity. If satisfactory tactile perception was obtained, pedicle screws were placed. This technique of pedicle screw placement was customary during the study period.

Group 1 patients had recording electrodes placed in muscles of interest; hence, handling of nerve roots may produce spontaneous response in the corresponding muscle. However, this recording cannot be continuous due to the use of muscle relaxants for anaesthesia; therefore, trigger EMG (t-EMG) was used to identify nerve root compromise following screw placement. Neuromuscular blocking agents were not used for at least 30 min prior to testing t-EMG. Disposable pedicle screw stimulating probes (Cadwell Laboratories Inc., Kennewick, WA, USA) which had a fully long insulated shaft terminating in a three millimetre ball tip was used to pass an electrical stimulus of up to 20 mA to the screw. Electrophysiological monitoring was conducted using Cascade Elite Intra-Operative Neuro-Monitoring (IONM) system (Cadwell Laboratories Inc., Kennewick, WA, USA). A positive response below 20 mA was considered as pedicle breach and a negative response was considered as accurately positioned. A positive response alerts the surgeon to attempt direct visualization of the medial pedicle wall. If the screw had violated the medial cortex, they were either revised or removed based on surgeon’s decision. Screw placement was also checked intraoperatively using x-ray images after completing the construct.

Group 2 patients had pedicle screws applied with similar technique except for the use of EMG. Screw positioning was checked only by means of intraoperative x-ray image after completing the construct. Post-operative X-rays were taken for all patients among both the groups. Further evaluation by CT scanning was arranged if there was clinical evidence of neurological compromise. If malpositioning

was determined by post-operative CT evidence, reoperation was performed to revise or remove the screw. Patient demographics, clinical presentation, indications for operation and operative variables were reviewed for each case. The efficacy of intraoperative EMG monitoring to identify screw breach and subsequent decrease in reoperation rates were evaluated.

Statistical analysis was performed using SPSS software v.18.0 for Windows (SPSS Inc., Chicago, IL, USA). Student's t-test was used for continuous variables and Fisher's exact test for categorical variables. A probability (p) value of <0.05 was considered statistically significant.

Results

We shortlisted 518 patients [mean age \pm standard deviation (SD) = 63.6 ± 11.5 years; 3112 pedicle screws] based on our inclusion criteria. Patients who received EMG monitoring throughout the procedure and t-EMG to determine screw placement were in Group 1 [$n = 296$; mean age = 64.2 ± 11.7 ; Screws = 1856]. The remaining patients who did not receive EMG monitoring were in Group 2 [$n = 222$; mean age = 62.9 ± 11.3 ; screws = 1256]. Demographic comparison between both groups was tabulated (Table 1). The groups were statistically similar in age [$p = 0.17$] and gender distribution [$p = 1$]; however, the overall number of screws and the number of screws per patient was more in Group 1.

Among 1856 screws in Group 1, 145 screws (7.8%) showed a positive response for t-EMG at stimulation thresholds ranging between 2.6 to 19.8 mA. Number of screws showing positive response at various threshold ranges was tabulated (Table 2). Even though 145 screws showed positive response, only 14 had actually breached the medial pedicle wall. This was determined based on intraoperative assessment by direct visualization of the medial cortex and X-ray images. Hence, there were 14 true positive (9.7%) and 131 false positive responses (90.3%).

Table 1 Demographic Data

Variables	Group 1	Group 2
No. of patients	$n = 296$ [Male = 106; Female = 190]	$n = 222$ [Male = 80; Female = 142]
Age	64.2 ± 11.7 years	62.9 ± 11.3 years
Total No. of pedicle screws	1856	1256
No. of screws per patient	6.3 ± 2	5.6 ± 2
No. of screws in L1	40	14
No. of screws in L2	162	64
No. of screws in L3	384	196
No. of screws in L4	542	396
No. of screws in L5	548	432
No. of screws in S1	180	154

Table 2 Overall number of screws that recorded positive response at various stimulation threshold ranges

No. of screws showing positive response	Stimulation threshold
6	<5 mA
26	5–10 mA
45	10–15 mA
68	15–20 mA

Various stimulation threshold ranges corresponding to true positive responses were tabulated (Table 3).

The remaining 1711 screws (92.2%) showed no response to t-EMG. However, one patient among those who had negative response for t-EMG, who had received posterior instrumentation from L2-L5, presented with postoperative clinical evidence of neurologic compromise. Postoperative CT scanning showed that one of the L2 screws had more than 25% of its diameter residing outside the medial pedicle wall, which required a revision surgery. The corresponding t-EMG recording was considered as a false negative response. This observation made us to analyse the sensitivity and specificity of t-EMG to diagnose potential pedicle breach, and was found to be 93.33% and 92.88% respectively (Table 4).

For those in Group 2 where EMG was not used, surgeon's tactile perception and intraoperative X-ray images were the only modalities to assess screw placement. Even though satisfactory screw placement was achieved intraoperatively, six patients had postoperative clinical evidence of neurologic compromise and CT scanning was done. Each of these patients had one screw that was identified to have breached the medial pedicle wall that prompted revision surgery. Our overall results indicated a significant decrease in the number of malpositioned screws that caused neurological compromise [$p = 0.02$], leading to subsequent decrease in reoperation rates [$p = 0.04$] among Group 1 patients (Table 5).

Discussion

Malpositioning of pedicle screws can lead to various complications (8). Screws breaching the pedicle pose a potential threat to adjacent neural structures and the most alarming consequence is neurological deficit. However, this can be avoided by meticulous technique. Recent advances in image guided navigation modalities

Table 3 Number of screws that recorded positive response which were true positive

No. of patients showing positive response	Stimulation threshold
3	<5 mA
9	5–10 mA
2	10–15 mA
0	15–20 mA

Table 4 – Sensitivity and specificity analysis

t-EMG Monitoring	Breached Pedicle (n)	Intact Pedicle (n)	Total
Positive	True positive = 14	False positive = 131	145
Negative	False Negative = 1	True Negative = 1710	1711
Total	15	1841	1856
Sensitivity	93.33%		
Specificity	92.88%		

that aid the surgeon to perform safe pedicle screw placements are gaining popularity [11, 12]. Yet, intraoperative neuromonitoring using continuous EMG and t-EMG are widely accepted as standard modalities [8, 13].

Continuous EMG monitoring acts as a real time monitor of spontaneous activity [14]. Any irritation to the nerve by stretch or compression causes trains of motor unit potential discharge in the corresponding muscle [14]. But the use of short acting neuromuscular blocking agents, interferes with this recording [15]. It is for this reason, neuromuscular blocking agents were not administered for at least 30 min prior to testing t-EMG. We stimulated the conductive pedicle screw head up to 20 mA and checked for response. A positive response at a relatively low threshold suggests definite malposition of the screw, violating the pedicle wall [10, 14, 16, 17].

Our analysis showed that a positive response to stimulation thresholds below 10 mA was highly suggestive of pedicle breach; but, a positive response for stimulation thresholds above 10 mA was frequently false positive [18]. Besides that, a negative response only suggests that the screw is not in proximity or abutting the nerve [10]. However, it may have violated the pedicle cortex, other than the medial wall, without troubling the nerve [19]. This was not confirmed with a routine CT evaluation. Even though such screws are not secure, they can still be considered safe, as they may not endanger neural integrity. These undetected breaches may compromise the stability of the construct and should be kept in mind [19]. However, it should be noted that, not all undetected breaches can cause symptoms. Based on our study, the symptom provoking pedicle breaches were those that breached the medial cortex, which was confirmed during the reoperation. In all such cases the screw was found to be abutting the nerve root which required repositioning. Other undetected breaches could have been present but never showed up symptomatically.

Table 5 – Results

Variable	Group 1	Group 2	Statistical analysis
No. of malpositioned screws causing neurologic compromise	1	6	$p = 0.02^*$
No. of patients who required reoperation	1	6	$p = 0.04^*$

*probability value "p" less than 0.05 was considered statistically significant

The one false negative response we encountered was perplexing as intraoperative EMG was negative but the patient had developed symptoms of neurological compromise which was later confirmed with CT, to have resulted from a malpositioned screw that had breached the medial cortex which required repositioning. This could have been avoided if intraoperative direct palpation of the medial cortex was routinely performed; however, we reserved it for those showing a positive response to t-EMG. Besides that, intraoperative perception that a screw had breached the medial cortex is not feasible always, especially if a thin layer of bone is still present over the screw [20]. Furthermore, in long constructs, we did not routinely perform a decompression favouring direct palpation of the medial cortex of the proximal most pedicle. If t-EMG had shown a positive response for such a proximal screw, redirecting the screw was first attempted. Subsequently, a laminotomy was performed to facilitate direct palpation of the medial cortex. By this way, we made sure that reoperation to reposition a malaligned screw is avoided; however, the need to attempt direct palpation or intra-operative repositioning completely depends on the t-EMG response.

Our results of sensitivity and specificity of t-EMG to detect potential pedicle breaches, is only with relation to symptomatic pedicle breaches where patients present with neurological deficits, and does not account for undetected pedicle breaches. Unlike other studies, our results showed high sensitivity for t-EMG monitoring (93.33%). This is because we had only one false negative response among 1711 screws and the false negativity of t-EMG was confirmed only with post-operative clinical examination. Various studies reported high specificity but not high sensitivity percentage; but unlike our study, they used post-operative CT to evaluate the status of the pedicles [10, 17, 21]. Hence, our analysis may be influenced by the uncertainty of true negatives due to lack of routine postoperative CT evaluation, which could have recognised more pedicle breaches, but was kept optional as the patients remained asymptomatic. Also, we only provided descriptive statistics for an analysis of stimulation threshold vs. sensitivity and specificity. However, this aspect was previously discussed in few studies [10, 22].

Considering all factors, depending solely on EMG monitoring may not be appropriate but when combined with other modalities, surgeons can benefit the most [7, 19]. Both palpatory and radiographic assessment needs to be reaffirmed by t-EMG monitoring. Furthermore, our most important finding was a significant decrease in reoperation rates with use of EMG monitoring [23]. This inference should be considered to outweigh all other uncertainties related to EMG monitoring.

Our analysis may be subject to secular influences regarding certain factors due to the retrospective nature

of this study. Regarding selection of samples, we only included patients with pedicle screws among L1-S1 segments, excluding dysmorphic pedicles. However, it should be understood that, not all pedicles are anatomically similar and there can be variants or anomalies [24, 25]. The underlying pathology for which the surgery was done may have affected the pedicle anatomy. The pedicles of patients in one group may be more prone for a breach when compared to the other group. This may have influenced our analysis of reoperation rates. The overall number of screws and the number of screws per patient in Group 1 was significantly higher than that of Group 2. Besides that, our decision to use intraoperative EMG was purely based on availability. These factors may have contributed for a selection bias and could have influenced our results.

Conclusion

We studied the efficacy of intraoperative EMG monitoring to detect potential pedicle breach during lumbar pedicle screw placement. Our results suggest that, t-EMG can be considered highly sensitive and specific for identifying potential pedicle breach by a malpositioned screw that can cause neurologic compromise; but, undetected breaches may still exist. However, t-EMG monitoring in combination with palpatory and radiographic assessment will certainly aid safe and secure pedicle screw placement. It can also efficiently reduce reoperation rates due to neurologic compromise provoked by a malpositioned screw.

Abbreviations

CT: Computed tomography; EMG: Electromyogram; SD: Standard deviation; t-EMG: Triggered electromyogram

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Availability of data and materials

The datasets used and analysed during the study are available from the corresponding author on reasonable request.

Authors' contributions

All authors made substantial contributions to concept and design. AKKP, JRC, TTT and PLL acquired the data. AKKP, JRC, CCN, TTT, LHC, WJC analysed and interpreted the data. AKKP, JRC, CCN, TTT and PLL drafted the manuscript and revised it critically for important intellectual content. All authors gave final approval of the version to be published.

Competing interests

There are no financial or non-financial competing interests.

Consent for publication

Not applicable.

Ethics approval and consent to participate

This study was approved by the institutional review board of Chang Gung Memorial Hospital (IRB No – 201601493B0) and was performed in

accordance with the ethical standards stated in the most recent version of the 1964 Declaration of Helsinki.

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